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Dynamical Inflation and Vacuum Selection

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Abstract

We consider an inflationary scenario where the energy scale of inflation stems from gauge theory dynamics. We point out its generic implications on vacuum selection of our universe, in particular, on determination of spacetime symmetries including its dimensions.

The energy scale of primordial inflation is supposed to be hierarchically below the gravitational scale in order to produce tiny fluctuations of the cosmic microwave background radiation [1]. The origin of the hierarchical scale of inflation may be dimensional transmutation induced by gauge theory dynamics.[1] The gauge theory dynamics for inflation is expected to cause profound effects on the evolution of the universe, since the inflationary process may determine the vacuum of our universe through dominant expansion of the spatial extension of the corresponding inflationary vacuum.

In this paper, we consider implications of this dynamical inflation on vacuum selection of our universe, in particular, on determination of spacetime symmetries including its dimensions.

Now we expose a mixed model of dilaton fixing [2] and topological inflation [3][2] as a simple example of dynamical inflation which incorporates an inflationary selection of the vacuum of our universe.

Let us consider a four-dimensional supersymmetric field theory with a dilaton Φ and an inflaton ϕ supermultiplets whose superpotential takes a form

$$W = Xf(\Phi) + Zh(\Phi)(1 - \lambda\phi^2), \tag{1}$$

where X and Z denote chiral superfields and $f(\Phi)$ and $h(\Phi)$ are functions of the dilaton superfield Φ:

$$f(\Phi) = f_1 e^{-a_1\Phi} - f_2 e^{-a_2\Phi}, \quad h(\Phi) = he^{-a\Phi}. \tag{2}$$

Here we set the gravitational scale equal to unity and regard it as a universal cutoff in the theory. We assume the couplings f_1, f_2, h and λ of order one and $0 < a_1 \sim a_2 \ll a$. This superpotential can be generated by dynamics of hypercolor gauge interactions where the dilaton-dependent scales $e^{-a_i\Phi}$ and $e^{-a\Phi}$ with a's related to β functions of the gauge interactions arise from hyperquark condensations with the aid of a superpotential considered in Ref.[2].

The potential in supergravity is given by

$$V = e^K(K_{AB}F^A F^{B*} - 3|W|^2), \tag{3}$$

[1]This is analogous to dynamical supersymmetry breaking, which may provide the origin of the hierarchically small scale of electroweak symmetry breaking.

[2]They are both R-invariant and so is the mixed model.

where K is a Kähler potential, K_{AB} denotes the inverse of the matrix

$$\frac{\partial^2 K}{\partial\phi_A \partial\phi_B^*}, \tag{4}$$

with $\phi_A = X, Z, \Phi, \phi$, and F^A is given by

$$F^A = \frac{\partial W}{\partial\phi_A} + \frac{\partial K}{\partial\phi_A} W. \tag{5}$$

For a generic Kähler potential, we have vacua of the model given by

$$F^A = W = 0, \tag{6}$$

which realizes the unbroken supersymmetry and R invariance. Hence the vacuum expectation values of the dilaton are determined by

$$f(\Phi) = 0, \tag{7}$$

which has runaway and fixed solutions,

$$\Phi \to \infty \tag{8}$$

and

$$\langle\Phi\rangle = \frac{1}{a_1 - a_2} \ln \frac{f_1}{f_2}, \tag{9}$$

respectively.[3]

For the fixed dilaton, from Eq.(6), we find $\langle X\rangle = \langle Z\rangle = 0$ and

$$\langle\phi\rangle = \pm\lambda^{-\frac{1}{2}}. \tag{10}$$

Since $|e^{-a_i\langle\Phi\rangle}| \gg |e^{-a\langle\Phi\rangle}|$, we may integrate out the superfields X and Φ to obtain an effective superpotential

$$W_{eff} = Zh(\langle\Phi\rangle)(1 - \lambda\phi^2), \tag{11}$$

which results in topological inflation between the two vacua Eq.(10) for appropriate values of the couplings [3]. Namely, once the dilaton is fixed, the universe may evolve through an inflationary stage.

[3] The gauge coupling constant g is given by $g^2 = 1/\mathrm{Re}\langle\Phi\rangle$.

On the other hand, the runaway vacuum $\Phi \to \infty$ yields a free theory, which induces no inflation.

Under the chaotic initial condition [4] of the dilaton field, the spatial extension of the vacuum corresponding to the fixed dilaton dominates through the inflationary process over that of the runaway vacuum [2].

Although we have provided a specific model, for definiteness, to demonstrate our point, the implications we consider in the dynamical inflation scenario seem rather generic. In the above model, the dilaton serves as an example of moduli[4] which determine the form of low-energy field theory describing our universe. Moduli are not necessarily usual moduli fields but may be any variables which parametrize the moduli space of underlying high-energy theory. The moduli space may be even disconnected, since the chaotic initial condition of moduli allows highly excited states which interpolate disconnected pieces of the moduli space.

For example, the spacetime dimension of the low-energy field theory may be determined by moduli which describe the size of the internal space of high-energy theory. Then the chaotic initial condition of those moduli implies that the spacetime dimension is determined through the inflationary process. If the corresponding inflation is dynamical, the spacetime dimension is expected to be four or less, since the dynamical scale due to gauge theory dynamics may not be generated in five or more dimensions.

In four dimensions, the presence of $\mathcal{N} = 1$ supersymmetry (and not $\mathcal{N} > 1$) may also originate from inflationary selection of this type, since it seems suitable for realizing scalar potentials which satisfy the slow-roll condition for inflation [1].

[4] For an investigation of stringy modular cosmology, see Ref.[5].

References

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